

Green Technologies for Energy-Efficient Buildings in Cold Climate Conditions of Russia

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Abstract. At present, energy preservation is the urgent task. Though Russia have all sufficient resources supplied to European and Asian countries, the abundance of fuel-power resources does not imply extravagance. The major objective of this study is to find out the application of green technologies into the buildings in the cold climate conditions of Russia. The present study describes a green methodology of building design and the approaches of green technologies implementation in Russia. The existing individual house in the village near Ekaterinburg, Russia, was used as an example to show the application of the green methodology suitable for this climatic conditions and to demonstrate the integration of energy-efficient architectural and engineering solutions into the building.

1. Introduction

Nowadays, energy preservation is the most burning international issue. Since Russia is a resource base for many European and Asian countries, there is no state of emergency to change the energy policy. First of all, energy preservation must be referred to a state strategic challenge [1]. The strategic objectives of energy saving are to improve energy efficiency and to determine the methods of energy efficiency improvement. The local conversion from fuel-power sources to renewable and sustainable ones enables developing sparsely populated and energy-decentralized territories. This approach is important since in 2016 the Program of Land Development of Russian's Far East was established. Land parcels in Primorsky Krai, Khabarovsk Krai, JEO, the Amur Region, Republic of Sakha (Yakutia), Magadan Region, Kamchatka Region, Sakhalin Region and Chukotka Autonomous Region are given for rent-free use to Russian citizens for five years. Total area of above listed regions is 6 169 329 km², and the average population density is 1.00 pop./km², that makes development increasingly difficult.

Furthermore, the strategies of the Arctic development are confirmed by the Russian government until 2020, are provided for using of the Arctic as a strategic resource base and and that of the conservation base of unique ecosystems. Distinctive features of the Arctic are extreme environmental conditions, including perennial ice cover, remoteness from major industrial clusters, high resource intensity and low sustainability of ecosystems [2]. Thus, energy-efficient innovative technologies, sustainable development and the use of renewable energy resources are aimed at creating healthy and



ecological environment [3]. Self-efficiency and sustainability of project facilities allow to take a new step in the land development [4].

2. Need for green policy in Russia

Energy preservation and energy efficiency issues in Russia could be determined only with the adoption of ecocentric thinking which signifies the identification of ecological factors in energy-efficient construction that allows to make the life green and shift to the path of sustainable development [3].

People spending most of their time in premises, and poorly designed, built or operating buildings result in human sickness and death. People often feel hot in summer and cold in winter, and the real danger is arisen if the energy supply is switched off. Research of WHO in 1998 had demonstrated that 30% of all new and modernized buildings are suffered from a syndrome of sick building, this means that inhabitants feel uncomfortable and even have serious problems with health during their life in such buildings [5].

Initially, the government support and legislative framework are urgent for local conversion to renewable resources [6]. For instance, EU energy policy is focused on energy consumption reduction in building sector, provision of secure and available energy supply, creation of competitive environment among power suppliers, and also assurance of stable energy consumption by means of energy efficiency promotion, reduction of greenhouse gases emissions and environmental pollution [7]. Such EU policy is sure to be determined by the dependence on fossil fuel producing countries, and consequently, on energy price instability for energy resources [8]. The introduction of innovative green technologies is mostly influenced by high prices for electricity and natural gas: the average price for electricity in EU is 0.25 €/kWh, in Russia it starts from 0.04 €/kWh, the average price for natural gas in EU accounts for 0.6 €/m³ and that in Russia is 0.08 €/m³ (Figure 1).

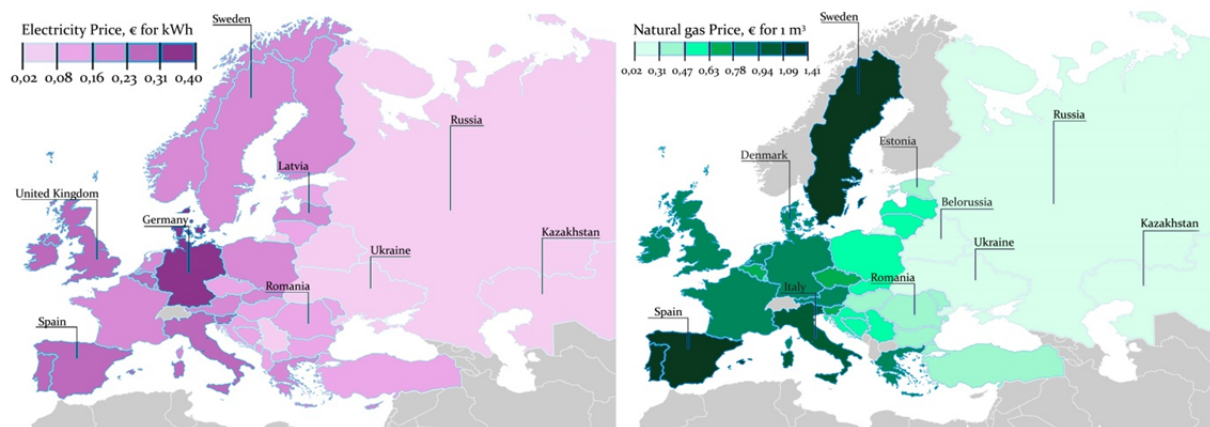


Figure 1. Electricity and natural gas prices maps of Russia and EU (2016).

3. Integration of green methodology into Russian climatic conditions

The whole complex designing process could be presented as a range of single parameters. No matter in what area and climatic conditions the building is designed, there is initial number of factors remaining constant. Firstly, it is the building shape both in the layout and cross-section that should be more compact, but taking into account day lighting. The building location on the site should consider passive solar design. Building orientation to the cardinal points analysis evaluates the most optimal location. The lack of angles in building allows to avoid supplemental thermal bridges and the most efficient building shape is a dome. Secondly, when designing a green building, we should take into account the materials it is built from that should be renewable and environmentally responsible, with zero or low off-gassing of harmful emissions [9]. Thirdly, the use of energy-saving supply and exhaust units with recuperative heat exchangers and geothermal heat exchangers leads to significant reduction

of energy consumption for heating and conditioning. The use of renewable energy is also possible in Russia, for instance, in the form of solar collectors, photovoltaic panels and wind turbines. Figures 2, 3, 4 show green technology implemented in some European counties.



Figure 2. Solar parabolic dish in University of Savona, Savona, Italy.



Figure 3. Solar panels in environmentally friendly production of pesto, Genova, Italy.



Figure 4. Green roof of shopping mall “Central”, Bratislava, Slovakia.

Russia has considerable untapped potential in wind power area. Strong orientation towards hydraulic power industry and coal-nuclear strategies, and the lack of need in another energy sources, especially in renewables, stall wind power development. The importance of energy power development in Russia results from 70% of Russian sparsely populated territory located in the zone of decentralized energy supply and being the potential wind resource zone [10].

High-potential wind energy market in Russia is characterized by vast amount of wind power sources:

- General wind power potential is estimated in 2000-3000 TWh/year.
- Economical wind power potential is estimated in 200-300 TWh/year.
- For the development of economical wind potential the construction of wind power plants (WPS) with total capacity of 100-150 GW is required.
- 1% of Russian territory is required to build WPS with total capacity of 150 GW [11].

Coastal areas are the most advanced areas for wind energy production [12]. In the majority of Russian regions annual average wind speed is lower than 5 m/s, for which reason conventional wind turbines with horizontal axis of rotation practically are not applicable, because their takeoff speed starts from 3-6 m/s. Therefore, wind turbines with vertical axis of rotation or rotor installations are appropriate in Russia.

Wind power is meant to be uncontrolled energy source. WPS output depends on wind strength which is exceptionally inconstant [13]. Hence, energy system itself has nonhomogeneity (peaks and breakdowns of energy consumption) and regulation of them by wind power is impossible. Consequently, wind power needs power system reserve, for instance, gas-turbine stations, and also smoothing mechanisms of nonhomogeneity of system output (hydro power plants (HPP) or pump storage power plant (PSPP)) [14].

4. Application of green technologies and principles in architectural design of an individual house in Ural region

One can refer to the project of the already constructed individual house in Beloyarskiy settlement near Yekaterinburg in Sverdlovsk region, Russia to illustrate the usage of above-mentioned green principles in the design of energy-efficient buildings. The project was created by the home owner

Sergey Vishnyakov. The country individual house was designed taking into account the climatic conditions of this built-up area, its function and orientation to the cardinal points.

4.1. Natural implication in housing design

The house was designed in building fathoms – “humanized”, anthropometric measures, that are human proportioned, convenient for artificial human habitat construction - architectural structures. Besides, in such “humanized” measures the special proportions are formed, which were selected by nature, for instance, bisection, golden ratio and its function. Therefore, in anthropometric measures nature harmony is found naturally [15]. The design was also carried out with adherence to the ancient Indian Vastu principles, that are directed to human-nature relations harmonization [16]. Based on Vastu, the rules of building construction of simple shape houses were defined and their specific principles are as follows: environment based site selection taking into account environment, right proportions, nontoxic and energy-saving construction [17]. Those principles are identical to those in sustainable architecture.

4.2. Description of constructive and architectural features

One of the first major distinctive features of the house in terms of energy efficiency is the building configuration – two-storied house with mansard and octagon in the layout. The general building volume is close to the dome, being the most efficient structure. The wall construction includes wooden frames, 250 mm thick KNAUF insulation, facade wooden board and air gap between insulation and facade covering. Triple-pane windows are made of low-emissivity glass and with argon flushing. There is a big 4mx4m window and the green house on the south side of the house, which allow to reduce energy consumption for heating (Figures 5, 6).

4.3. Present engineering solutions

In external walls energy-saving supply and exhaust units with recuperative heat exchangers are integrated to create optimal and comfort microclimate in rooms. In the individual house the electric boiler is used as a major heating source, domestic hot water (DHW) in summer period is carried out by vacuum solar collectors, and if the heating energy produced by collectors is not enough, then heating of water is produced by electric heating units that are embedded into the boiler. In the house the wood-burning stove is installed as a standby heating source. To increase stove efficiency, the system of external air supply for combustion with preheating in geothermal heat exchanger is implemented. The geothermal heat exchanger itself is a serpentine tube deposited under the depth of ground freezing. The system consisting of photovoltaic panels (Figure 7), controller, battery and inverter was designed for fractional conservation of electrical demand (for lighting and domestic needs).



Figure 5. South facade of individual house.

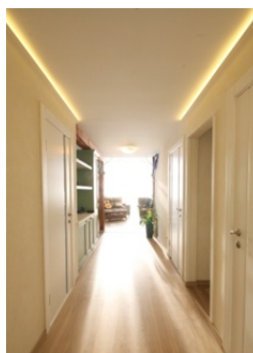


Figure 6. Inside view to the south.



Figure 7. Photovoltaic panels on the roof.

4.4. Special measures for reduction of electric energy consumption

To increase energy efficiency and reduce electric energy consumption, several additional measures should be implemented in heating and hot-water supply systems. As a major heating and hot-water supply system source (in periods when solar collectors are not able to provide hot water requirements) the geothermal heat pump should be applied. Provisions should also be made for heat accumulator and additional serpentine tube in hot water boiler. Figure 8 shows the principal scheme of such engineering systems.

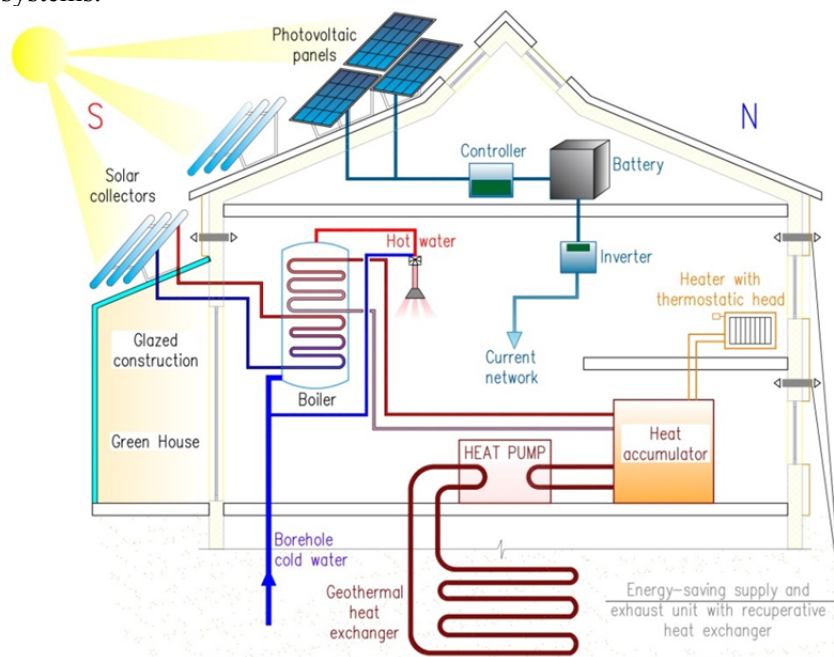


Figure 8. The principal scheme of engineering systems.

4.4.1. Description of the engineering system work in winter period. Heat pump is a major heating energy source that provides a heat carrying agent to be heated for DHW and heating systems. To increase economic viability, the heat accumulator installation is provided, thus, heat pump is working only at night time when electricity is cheaper than in the daytime. The heat carrying agents in a heat accumulator having been heated during the night, the heat pump turns off. The next day the heating energy that is reserved in heat accumulator is consumed. Consequently, the electricity costs in the system under review will decrease 6-7 times compared with those of present engineering systems:

$$N \times (t_d \times p_d + t_n \times p_n) = C \quad (1)$$

$$\frac{3N}{PCP} \times t_n \times p_n = C \quad (2)$$

Total maximum costs using the electric boiler with a capacity of 9 kW under peak load are 676,08 RUB ≈ 10,56 € per day, as in equation (1), where N - boiler capacity, [kW]; t_d , t_n - duration of day and night tariffs in Yekaterinburg, [h]; p_d , p_n - day and night electricity tariff costs [RUB]. Under the use of the heat pump with the heat accumulator the total costs decrease almost 7 times. In equation (2) required capacity of the pump equals triple capacities of the electric boiler, since the heat pump works only at night ($t_n/24=3$), where PCP is a productivity coefficient of the pump (3...4,5). As a result, the total costs equal 103,10 RUB ≈ 1,61 € per day.

4.4.2. Description of the engineering system work in summer period. DHW of the individual house in summer period is carried out by vacuum solar collectors that provide the electric boiler heating. The heat pump converts to "reverse" mode functioning as a conditioner. Space cooling is performed by means of cooled water distribution to heating units of the individual house. However, the operation

cycle is analogous to the heating mode. Thus, the use of the heat pump and the heat accumulator provides comfort conditions in private premises. In addition, electricity costs in average are 2 times lower those in standard split-system AC units.

5. Conclusions

Energy preservation issue is feasible even in severe climatic conditions [18]. This question should be handled in an integrated manner starting from building location on the site, orientation to the cardinal points, building configuration, possibilities of renewable energy sources usage and potential variations of energy consumption reduction methods. However, the problem is hardly to be solved without the government support in energy efficiency technology implementation.

References

- [1] Hafezalkotob A 2017 Competition, cooperation, and coopetition of green supply chains under regulations on energy saving levels *Transportation Research Part E: Logistics and Transportation Review* **97** pp 228–50
- [2] *The strategies of the development of the Arctic until 2020* Retrieved from <http://government.ru/info/18360/>
- [3] Leyzerova A, Sharovarova E and Alekhin V 2016 Sustainable strategies of urban planning *Procedia Engineering* **150** pp 2055–61
- [4] Waite J 2017 Land reuse in support of renewable energy development *Land Use Policy* **66** 105
- [5] Dvoretzky A 2017 Passive solar heating of buildings in south climatic conditions of Russia *Collection of Scientific Works of Russian Academy of Architecture and Construction Science* **2** pp 151–159
- [6] Dreidi M, Mokhlis H and Mekhilef S 2017 Inertia response and frequency control techniques for renewable energy sources: A review *Renewable and Sustainable Energy Reviews* **69** pp 144–55
- [7] Boeters S and Koornneef J 2011 Supply of renewable energy sources and the cost of EU climate policy *Energy Economics* **33** pp 1024–34
- [8] Capros P, Paroussos L, Charalampidis I, Fragkiadakis K, Karkatsoulis P and Tsani S 2016 Assessment of the macroeconomic and sectoral effects of higher electricity and gas prices in the EU: A general equilibrium modeling approach *Energy Strategy Reviews* **9** pp 18–27
- [9] Ragheb A, El-Shimy H and Raghed G 2016 Green architecture: A concept of sustainability. *Procedia-Social and Behavioral Sciences* **216** pp 778–87
- [10] Parmukhina E 2010 Wind energy market *Electrotechnical market* **1** p 32
- [11] Kulakov A 2011 Wind energy in Russia: development challenges and prospects *Energy Board* **5** p 37
- [12] Mazon J, Rojas J, Jordi J, Valle A, Olmeda D and Sanchez C 2015 An assessment of the sea breeze energy potential using small wind turbines in peri-urban coastal areas *Journal of Wind Engineering and Industrial Aerodynamics* **139** 1–7
- [13] Dumitru C and Grigor A 2017 A Daily average wind energy forecasting using artificial Neural networks *Procedia Engineering* **181** pp 829–36
- [14] Liu F, Bie Z, Liu S and Ding T 2017 Day-ahead optimal dispatch for wind integrated power system considering zonal reserve requirements *Applied Energy* **188** pp 399–408
- [15] Kozodaeva N 2011 Evolution of architectural system of measures, the Architect Math *Analytics of Cultural Studies* **21** pp 25–36
- [16] Iovlev V 2011 Architectural and environmental topology of ethnic spaces *Akademicheskyy Vestnik UralNIIProekt RAASN* **2** pp 49–51
- [17] Ulciferov O 2013 Interaction between literature and art of major religious and cultural systems in India *Vestnik MGIMO* **1** pp 162–170
- [18] Nord N 2017 Building energy efficiency in cold climates *Reference module in earth systems and Environmental Sciences*